TM-(L)-1272/000/00

TECHNICAL MEMORANDUM

(TM Series)

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Satellite Computer Program Description
Milestone 5
Computer Shadow Times (SHADOW)

by

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22 May 1963

Approved
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1.0 IDENTIFICATION

1.1 Compute shadow times (SHADOW). L45 MOD AA.

1.2 By C. M. Seacat, 15 May 1963

1.3 System Development Corporation, Sunnyvale, California

2.0 PURPOSE

SHADOW is a 1604 COP-controlled program to compute the times at which a satellite enters and leaves the shadow of the earth. Results are printed on-line and off-line.

3.0 USAGE

3.1 Calling Sequence

The program is normally called by a function card with the format:

```
*SHADOW  A  B  C  D  E  F.F  G  H  I  J  K.K
```

A	Vehicle number		
B	Month		
C	Day		
D	Hour		Start Time
E	Minute		
F.F	Second	(Floating Point)	
G	Month		
H	Day		
I	Hour		Stop Time
J	Minute		
K.K	Second	(Floating Point)	

An option exists to specify start and stop times by rev number. The function card format is:

```
*SHADOW  A  B.  C.
```

A Vehicle Number

B Starting Rev (decimal point mandatory)

C Ending Rev (decimal point mandatory)

A fractional rev number may be input without harming the program, but the fractional part will be ignored. For consistency between the function card and printed output, it is recommended that zero, or blank, follow the decimal point in the rev number. Calculations are carried out to, but not including, the terminal rev. In this option starting rev must be 1. or greater.
Reset tapes containing orbital conditions must be mounted on tape drives 2, 9 and 10.

There are no unexplained halts in the program with one exception. Early in the program the subroutine SETUP is called. If reset tape and reference pool parameters are not correct SETUP will halt due to an erroneous return jump. The trouble is likely to be in the timing area, for example a launch time earlier than MONTHB in the reference pool.

3.2 OUTPUTS

Every time the satellite leaves the shadow of the earth, the program prints on line the date, time, rev number, geodetic latitude, and longitude at which it entered and left. When the stop time is reached, the program prints out the percentage of time in shadow, i. e., the sum of all the shaded periods divided by the time range on the function card.

If the satellite does not enter shadow for a particular rev this information is printed.

If the orbit decays during the time span of the function card this information is printed.

All output is on-line and duplicated off-line (tape 3). Figure 1 shows sample printouts.

SAMPLE PRINTOUTS

VEH 1136 RUN NO. SAMPLE99
SHADOW INTERVALS TABULATED BELOW

ENTER							LEAVE						ENTER		LEAVE	
MO	DY	HR	MN	SEC	SYSTEM	REV	HR	MN	SEC	SYSTEM	REV	DURATION	GEOD LAT	LONG	GEOD LAT	LONG
11	1	12	25	0	44700.	9.8	13	0	0	46800.	10.2	2100.	53 15.9S	179 14.2E	83 59.6N	170 27.8E
11	1	13	55	0	50100.	10.8	14	30	0	52200.	11.3	2100.	47 49.4S	156 40.5E	85 35.9N	32 5.9W
										. . (etc) . .						
11	2	10	35	0	38100.	24.8	11	10	0	40200.	25.2	2100.	52 44.7S	154 10.4W	89 30.5N	162 56.9W

TOTAL SHADOW TIME 354000. SECONDS FOR 41. PERCENT

REV 10.7 SHADOW PERIOD LESS THAN ONE MINUTE

ORBIT HAS DECAYED

FIGURE 1.

To start from scratch, the following function sequence is recommended:

*IRT ...
*WNRT ... (Each card completed appropriately)
*INJFUN ...
*SHADOW ...

4.0 METHOD

4.1 Mathematical Formulation

The following assumptions are made:

a. the shadow of the earth is cylindrical and non-fuzzy.
b. the positions of the satellite and the sun are known for a given time, t, in inertial coordinates.

The coordinates of the sun at time t are (x, y, z). The axis of the cylinder formed by the shadow of the earth passes through the point (-x, -y, -z).

The coordinates of the satellite at time t are (ξ, η, ζ).

The equation $\rho^2 = \xi^2 + \eta^2 + \zeta^2$ defines an earth-centered sphere of radius ρ, with the satellite on the surface.

The axis of the cylindrical shadow pierces this sphere at (x', y', z'), where:

$$x' = -\frac{\rho x}{R}$$

$$y' = -\frac{\rho y}{R}$$

$$z' = -\frac{\rho z}{R}$$

$$R = \sqrt{x^2 + y^2 + z^2}$$, distance of sun at time t

The geometry is illustrated in Figure 2.

The distance, d, from (x', y', z') to the circular intersection of the cylinder and the sphere is given by:

$$d^2 = 2\rho\left(\rho - \sqrt{\rho^2 - r^2}\right)$$ where r = earth radius.

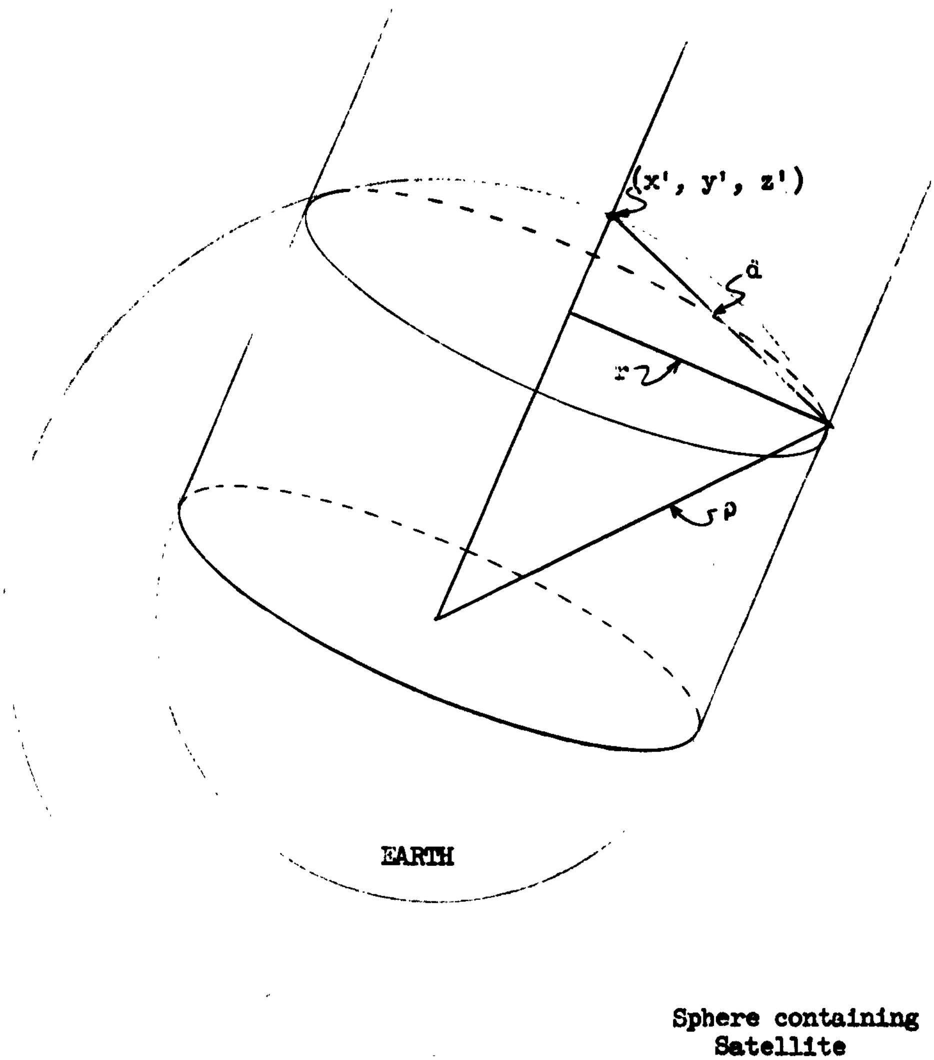

FIGURE 2. GEOMETRICAL REPRESENTATION

The distance, D, from (x', y', z') to the satellite is given by

$$D^2 = (x' - \xi)^2 + (y' - \eta)^2 + (z' - \zeta)^2$$

If $D^2 > d^2$, the satellite is in sunlight.

If $D^2 \leq d^2$, the satellite is in shadow.

Please note that the analysis above does not assume a circular or near-circular orbit. A new ρ is computed for each t.

4.2 Coordinate Determination

The program computes the inertial coordinates of the satellite at time t by the subroutines TTE and PTR.

The coordinates of the sun are computed by the program using an approximation technique based on the near-sinusoidal variation in sun coordinates as a function of time. The crucial parameters are the equinoces (at which time y and z are zero), the times at which y and z are maximum and minimum, the times at which x is maximum and minimum, and the respective maximum and minimum values. Figure 3 is a plot of sun x, y and z against time.

The trick is to fit x, y, and z with sine/cosine curves as nearly as possible. Each curve in figure 1. is broken into three parts: pre-vernal equinox, between equinoces, and post-autummal equinox. (In the case of x, the schisms are not exactly at the equinoces, but at the maximum and minimum values, which are close to the equinoces). A slightly different period is used for each case, the choice depending on where in the calendar year t falls. The amplitude of y and z are slightly different outside the equinoces than between them, for which the program compensates. Finally, x is adjusted downward by a constant amount. Examination of the table below and the pertinent sections of the flow charts will clarify the details of this technique.

The program will be valid as is through 1972. At that time the parameters tabulated below should be re-computed and the tagged locations updated.

TAG	UNITS	SCALING	DESCRIPTION
XBASE	Hours	Floating Point	Time at which x is maximum
YBASE	Hours	Floating Point	Vernal equinox (y, z = 0)
XPER	Hours	Floating Point	Difference between times at which x is maximum and minimum.
YPER	Hours	Floating Point	Difference between equinoces.

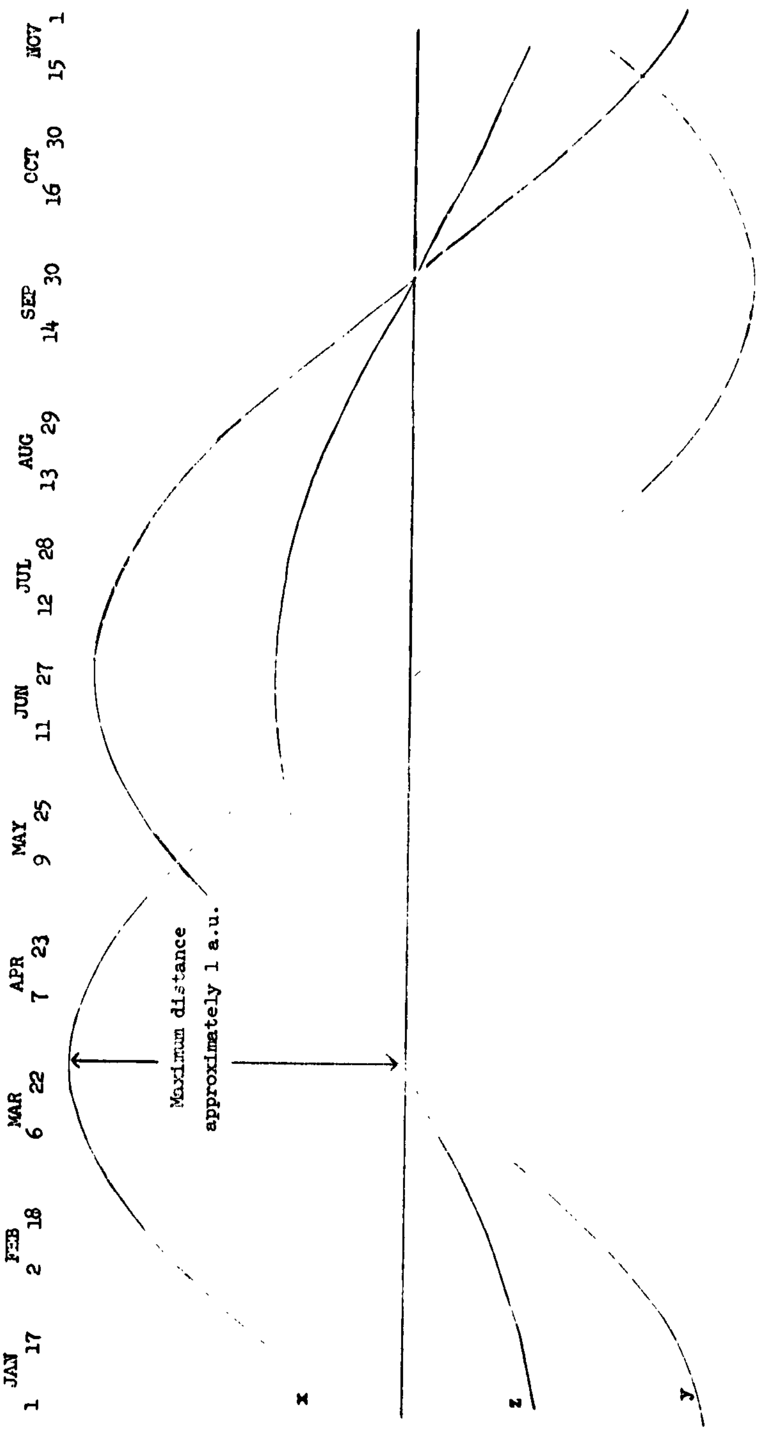

FIGURE 3. SUN COORDINATES VERSUS TIME

TAG	UNITS	SCALING	DESCRIPTION
XPERN	Hours	Floating Point	Twice the interval between XBASE and the time in the preceding year at which x is equal to XADJ, defined below. This time will be close to the last year's winter solstice.
XPERN1	Hours	Floating Point	Twice the interval between the time at which x is minimum and the time this year that x equals XADJ, defined below. This time will be near this year's winter solstice.
YPERN	Hours	Floating Point	Twice the interval between the time at which y is minimum the preceding year (near winter solstice) and this year's vernal equinox.
YPERN1	Hours	Floating Point	Twice the interval between this year's autumnal equinox and the time at which y is minimum this year (near winter solstice).
XADJ	None	Floating Point	Minus one half the sum of the maximum and minimum values of x.
YNORMP	None	Floating Point	The maximum value of y.
YNORMN	None	Floating Point	The absolute value of the minimum value of y.
ZNORMP	None	Floating Point	The maximum value of z.
ZNORMN	None	Floating Point	The absolute value of the minimum value of z.
THISYR	Integer	Right Just	The year for which these calculations are being made.
XBASES	Hours	Floating Point	XBASE for this year
XBASES+1	Hours	Floating Point	XBASE + 6.15 hours for next year.

TAG	UNITS	SCALING	DESCRIPTION
XBASES+2	Hours	Floating Point	Last entry plus 6.15 hours for next year
.	.	.	.
.	.	.	.
etc	.	.	etc
.	.	.	.
.	.	.	.
XBASES+9	Hours	Floating Point	Note: Subtract 24 from entries corresponding to year after leap year.
YBASES	Hours	Floating Point	YBASE for this year
YBASES+1	Hours	Floating Point	YBASE + 6.15 hours
.	.	.	.
.	.	.	.
etc	.	.	.
.	.	.	.
.	.	.	.
YBASES+9	Hours	Floating Point	(Same as above, for Y)

The inertial coordinates of the sun for a given year are tabulated in the American Ephemeris and Nautical Almanac. This volume should be used to compute the parameters required. YNORMP, YNORMN, ZNORMP, and ZNORMN are transcribed directly from the almanac. Appropriate conversion is done by the program.

4.3 Detailed Program Processes

When first entered, the program searches for the boundaries of the shadow. This is done by incrementing TAU by one-eighth of a period, computing orbital elements, and applying the equations of section 4.1. When the satellite is found to be in shadow, the search interval is reduced to one minute, and the orbit advanced from the last known time it was in sunlight (one-eighth period ago) in one minute increments until it again enters shadow. The corresponding time and position are saved. The orbit is advanced in one-minute intervals until the satellite enters sunshine. One line of data is printed.

If the satellite was in shadow at the starting time of the function card, the "search" logic just described is repeated, starting at the time the satellite entered sunshine. Thus after one or two revs the shadow boundaries have been determined to within one minute. Accordingly, the first and perhaps the second line of printout show one-minute precision.

After the boundaries are determined, the orbit is updated to last time of entry into shadow plus the orbital period. TAU is advanced or regressed in one-minute increments until the start of shadow is bracketed, then advanced from sunlight to shadow in one-second intervals. The time of entry is again saved. This time is increased by the length of time in shadow last rev, end of shadow bracketed to within a minute, and finally resolved to one second. One line of data is printed out. This and subsequent printouts show one second precision. This is repeated until TAU exceeds stop time from the function card. This logic is based on the fact that due to the slow change in sun position, successive entering times are close to a period apart. However, sun position is recomputed for each TAU.

If the shadow interval is less than one minute for a particular rev, this is printed out for each rev that it occurs. After the first occurrence of total sunshine the search logic is repeated until shadow intervals exceed one minute. No harm is done if the satellite starts in total sunshine.

Detailed flow charts may be found in section 10.0.

5.0 RESTRICTIONS

5.1 Accuracy

It was noted in the preceding section that once the program got off the ground results were printed to the nearest second. Bear in mind that this is merely the precision to which the program computes and should not be construed as a claim of one second accuracy.

Regarding accuracy, the two major error contributors are the approximation of sun coordinates by sine curves, and the assumption that the earth's shadow is a cylinder without penumbra. (Erroneous orbital prediction may be discounted).

The maximum relative error due to sun position approximation is $\pm$ .001.

The earth umbra is of course conical. The ratio of height to base radius is about 410 to 1, suggesting a relative error increase of about .002 for each earth radius the satellite is distant.

The effect of the penumbra will not be considered except to point out that it would tend to make some arbitrarily defined "mean shadow" (e.g., half-way into the penumbra) more nearly cylindrical. Refraction, however, works against this, having the effect of shortening the earth shadow core.

These error limits are well within tolerances of expected users of the program.

5.2 Hardware Requirements

One 1604 computer plus normal peripheral equipment.

5.3 Subroutines

The program uses the following subroutines.

Code Name	Code Name
RESET	FIX
PTR	RALONG
LTT	UTMAC
TTE	MACGUT
SETUP	SQRT
SUBERR	ATAN1
RADDEG	COS
OUTPUT	SIN
FLOAT	TAN

The program uses the Breakwell closed form equations. This introduces some (not well defined) restrictions as to admissible orbital eccentricity and magnitude of semi-major axis. Pending further study, all that can be said is try it and see. Difficulties, if any, will occur in TTE.

5.4 Reference Pool

The program refers to the following items:

Symbol	Set	Used
BLATE		x
BWPER		x
CLOCK	x	x
DAY	x	x
DAYTAB		x
DEG	x	x
HRS	x	x
IDBCD		x
LAT	x	x
MIN	x	x
MONTH	x	x
RA	x	x
RAD	x	x
RE		x
REV	x	x
SEC	x	x
TAU	x	x
X	x	x
Y	x	x
YEARB		x
Z	x	x

6.0 TIMING

The program requires at most three seconds per rev, and about one second per rev average, including output time.

7.0 STORAGE REQUIREMENTS

The program SHADOW occupies 470 cells, plus 42 spares for 512 (1000_8). Subroutine requirements can be ascertained from the following storage analysis:

STORAGE ANALYSIS

(* = RELOCATABLE N = NEWLY DEFINED R = REDEFINITION)

	Name	Address	Name	Address
	RESET	* 11000	UTMAC	* 21232
	TTE	* 21541	FLOATBIN	* 22726
	RADDEG	* 22544	ATAN1	* 22460
	FIX	* 21203	SIN	* 22252
	MACTIM	* 22630	LTT	* 21252
	UNPACK	* 22714	SUBERR	* 20520
	ATAN2	* 22744	FLOAT	* 22154
	COS	* 22167	RALONG	* 22573
N	SHADOW	* 10000	MACGUT	* 21443
	PTR	* 22067	SQRT	* 22336
	SETUP	* 17123	ASIN	* 23057
	OUTPUT	* 17176	TAN	* 22375
	REDLO	* 22604		

8.0 VALIDATION AND TEST CASES

In order to verify program outputs the following tests were performed. Function cards and pertinent computer output are shown with each test.

8.1 Test 1. The injection vector was chosen so that the orbit be as nearly circular as possible, be perfectly polar, contain the sun in its plane at the summer solstice, and have a zero drag factor. Under these conditions the shadow interval should be maximum at the summer and winter solstice. Furthermore, it is possible to examine the cross section of the earth and satellite orbit cut by the orbital plane to check the entering and leaving latitudes output by the program. Figures 4 and 5 show the results.

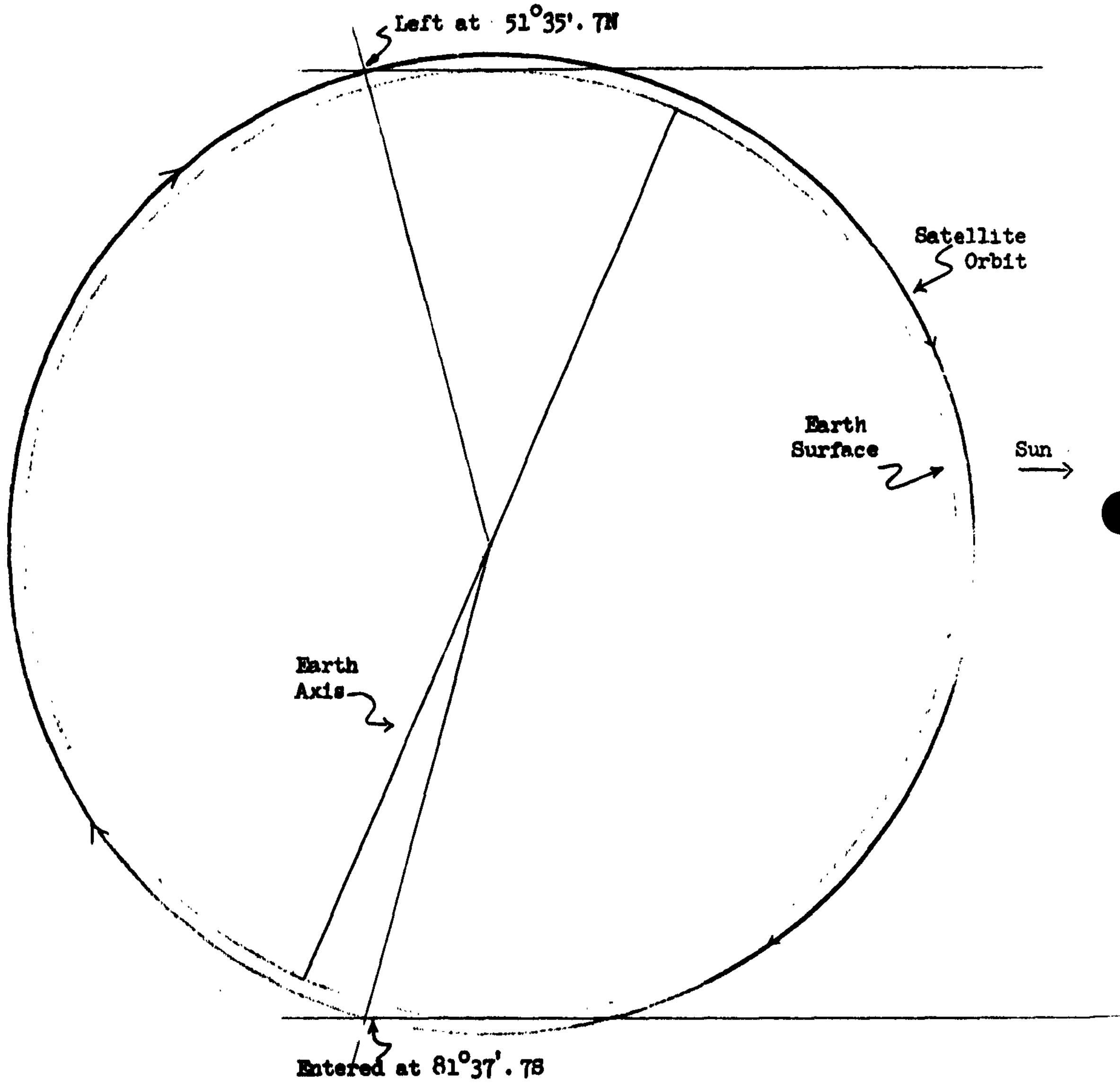

FIGURE 4.

CROSS SECTION, ORBITAL PLANE CONTAINING SUN AT SUMMER SOLSTICE

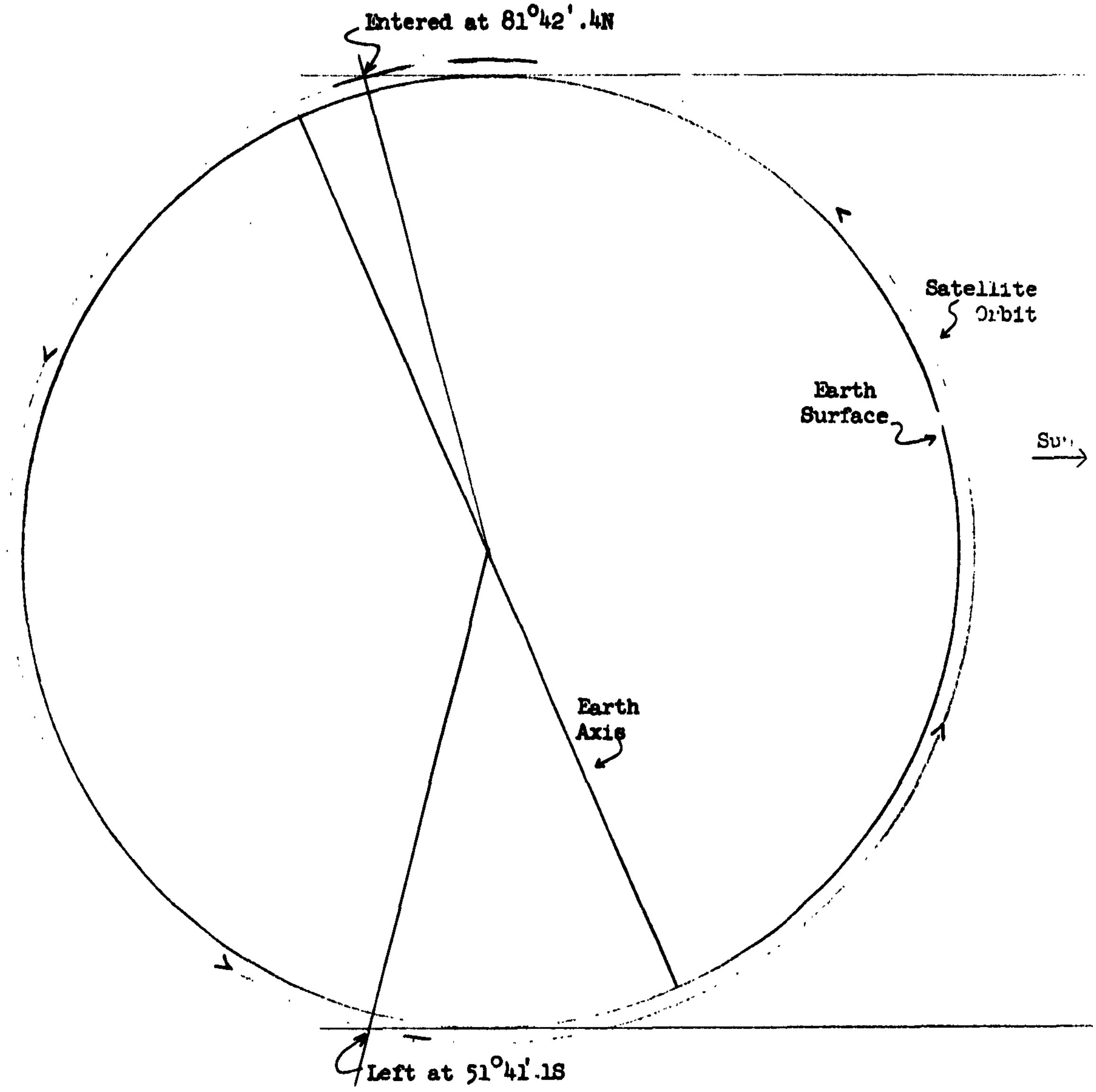

FIGURE 5.

CROSS SECTION, ORBITAL PLANE CONTAINING SUN AT WINTER SOLSTICE

Function Cards and Results

```
* WNRT 1136 0 0
R  37     DEC      0
R  46     DEC      0
R  60     DEC      0
          END
* TIME 1136 1 1 6 20 19 42 20.95
* TIME 1136 1 2 6 20 19 44 55.58
* TIME 1136 1 3 6 20 19 45 32.28
* TIME 1136 1 4 6 20 19 49 36.
* INJFUN 1136 0 -25525. -270. +22.7 +117.4 -692250. 0.0 0
* CLR
* CARDS
DEFINE SHADOW 3000
(BINARY DECK)
* SHADOW 1136 6 20 20 0 0.0 6 24 0 0 0.0
```

VEH 1136 RUN NO. TST11MAY

SHADOW INTERVALS TABULATED BELOW

ENTER							LEAVE					
MO	DY	HR	MN	SEC	SYSTEM	REV	HR	MN	SEC	SYSTEM	REV	DURATION
		⋮								⋮		
6	21	5	7	13.	18433.	6.7	5	44	7.	20647.	7.1	2214.
6	21	6	35	52.	23752	7.7	7	12	46.	25966.	8.1	2214.
6	21	8	4	32.	29072.	8.7	8	41	26.	31286.	9.1	2214.
6	21	9	33	11.	34391.	9.7	10	10	5.	36605.	10.1	2214.
6	21	11	1	51.	39711.	10.7	11	38	45.	41925.	11.1	2214.
		⋮								⋮		
6	23	5	52	56.	21176.	39.7	6	29	50.	23390.	40.1	2214.
6	23	7	21	35.	26495	40.7	7	58	28.	28708.	41.1	2213.
6	23	8	50	15	31815	41.7	9	27	8.	34028.	42.1	2213.
6	23	10	18	54.	37134.	42.7	10	55	47.	39347.	43.1	2213.
6	23	11	47	34.	42454.	43.7	12	24	27.	44667.	44.1	2213.

```
* SHADOW 1136 12 20 0 0 0.0 12 24 0 0 0.0

                    VEH 1136 RUN NO. TST11MAY
                  SHADOW INTERVALS TABULATED BELOW

ENTER                              LEAVE

MO DY HR MN SEC  SYSTEM   REV     HR MN SEC SYSTEM   REV     DURATION
       :                                     :
12 20  7 13 40.  26020.2964.2      7 50 32. 28232.2964.6      2212.
12 20  8 42 19.  31339.2965.2      9 19 11. 33551.2965.6      2212.
12 20 10 10 58.  36658.2966.2     10 47 51. 38871.2966.6      2213.
12 20 11 39 37.  41977.2967.2     12 16 30. 44190.2968.6      2213.
12 20 13  8 17.  47297.2968.2     13 45 10. 49510.2968.6      2213.
       :                                     :
12 23  1  43 16.  6196.3009.2      2 20  9.  8409.3009.6      2213.
12 23  3  11 55. 11515.3010.2      3 48 48. 13728.3010.6      2213.
12 23  4  40 34. 16834.3011.2      5 17 27. 19047.3011.6      2213.
```

8.2 Test 2. With the orbit defined in Test 1. the shadow period should be zero around the autumnal equinox. Manual calculations showed that the satellite should be in total sunshine from the first week in September to the first week in October.

Function Cards and Results

```
* SHADOW 1136 9 4 20 0 0.0 9 7 20 0 0.0

                    VEH 1136 RUN NO. TST11MAY
                  SHADOW INTERVALS TABULATED BELOW

ENTER                              LEAVE

MO DY HR MN SEC  SYSTEM   REV     HR MN SEC  SYSTEM   REV     DURATION
       :                                      :
 9  6 10 19 55.  37195.1260.9     10 24 33.  37473.1260.9      278.
 9  6 11 48 48.  42528.1261.9     11 52 58.  42778.1261.9      250.
 9  6 13 18  2.  47882.1262.9     13 21  3.  48063.1262.9      181.
 9  6 14 47  5.  53225.1263.9     14 49 18.  53358.1263.9      133.
REV1264.9 SHADOW PERIOD LESS THAN ONE MINUTE
REV1265.9 SHADOW PERIOD LESS THAN ONE MINUTE
REV1267.0 SHADOW PERIOD LESS THAN ONE MINUTE
```

```
* SHADOW 1136 10 6 12 0 0.0 10 8 12 0 0.0

                    VEH 1136 RUN NO. TST11MAY
                  SHADOW INTERVALS TABULATED BELOW

ENTER                                  LEAVE

MO DY HR MN SEC  SYSTEM  REV      HR MN SEC  SYSTEM  REV      DURATION
       .                                       .
       .                                       .
       .                                       .
REV1763.5 SHADOW PERIOD LESS THAN ONE MINUTE
REV1764.4 SHADOW PERIOD LESS THAN ONE MINUTE
REV1765.5 SHADOW PERIOD LESS THAN ONE MINUTE
REV1766.5 SHADOW PERIOD LESS THAN ONE MINUTE
10  7 14 47 26.  53246.1767.4    14 51 26.  53486.1767.5     240.
10  7 16 15  6.  58506.1768.4    16 19 52.  58792.1769.4     286.
10  7 17 43 33.  63813.1769.4    17 48 43.  64123.1769.5     310.
10  7 19 11 49.  69109.1770.4    19 17 44.  69464.1770.5     355.
```

8.3 Test 3. An actual bird observed to enter sunlight at a particular rev. This orbit was recreated and the program was run over the time in question. This happened to be a relatively eccentric orbit. Program output agreed with what was expected.

<u>Function Cards and Results</u>

```
* TIME 1136 1 1 12 23 4 29 48.
                                    RESET TAPES 9, 10
* TIME 1136 1 2 12 23 4 32 48.
                                    RESET TAPES 2, 9
* TIME 1136 1 3 12 23 4 33 8.
                                    RESET TAPES 10, 2
* TIME 1136 1 4 12 23 4 38 8.
                                    RESET TAPES 9, 10
* INJFUN 1136 0 -27307.  +158.54 +23.26 +149.14 -922500. +2.31 0

* CLR

* CARDS

DEFINES SHADOW 3000

* SHADOW 1136 11. 30.
```

VEH 1136 RUN NO. TST11MAY

SHADOW INTERVALS TABULATED BELOW

ENTER							LEAVE						
MO	DY	HR	MN	SEC	SYSTEM	REV	HR	MN	SEC	SYSTEM	REV	DURATION
12	24	1	52	58.	6778.	11.4	1	58	58.	7138.	11.4	360.
12	24	3	49	13.	13753.	12.4	3	54	25.	14065.	12.4	312.
12	24	5	45	45.	20745.	13.4	5	50	17.	21017.	13.4	272.
12	24	7	42	22.	27742.	14.4	7	46	6.	27966.	14.4	224.
12	24	9	39	5.	34745.	15.4	9	41	48.	34908.	15.4	163.
12	24	11	36	10.	41770.	16.4	11	37	7.	41827.	16.4	57.

REV 17.4 SHADOW PERIOD LESS THAN ONE MINUTE
REV 18.4 SHADOW PERIOD LESS THAN ONE MINUTE

8.4 Test 4. In another actual case the time of entry into sunlight was known (at least approximately) from telemetry. A reset tape was borrowed in order to test the program against this data. The times differed by 16 seconds.

8.5 Test 5. Results from a similar program for a 7090 computer were made available, plus corresponding injection conditions. The greatest error in fourteen comparisons was 40 seconds. No systematic bias was evident. The reported accuracy of the 7090 program is approximately one minute.

<u>Function Cards and Results</u>

```
* TIME 1136 1 1 6 2 9 52 43.95
                                    RESET TAPES 2, 9
* TIME 1136 1 2 6 2 9 55 17.58
                                    RESET TAPES 10, 2
* TIME 1136 1 3 6 2 9 55 54.28
                                    RESET TAPES 9, 10
* TIME 1136 1 4 6 2 10 0 0.0
                                    RESET TAPES 2, 9
* INJFUN 1136 0 -27922.473 +8.54 +15.421 +152.953 -1223407.5  -.326  0

* CLR

* CARDS

DEFINES SHADOW 3000

* SHADOW 1136 6 2 10 10 0.0 6 4 20 0 0.0
```

VEH 1136 RUN NO. TST11MAY

SHADOW INTERVALS TABULATED BELOW

ENTER							LEAVE				
MO	DY	HR	MN	SEC	SYSTEM	(7090 PGM)	HR	MN	SEC	SYSTEM	(7090 PGM)
6	2	11	52	28.	42748.	42720.	12	22	28.	44548.	44580.
6	2	14	6	54.	50814.	50820.	14	37	20.	52640.	52680.
6	2	16	22	.	58920.	58920.	16	52	26.	60746.	60780.
6	2	18	37	8.	67028.	67020.	19	7	32.	68852.	68880.
6	2	20	52	15.	75135.	75120.	21	22	38.	76958.	76980.

(Note that 7090 System Times are divisible by 60, consistent with the alleged one-minute program accuracy).

8.6 Test 6. In order to gauge the effect of approximating sun position by sine curves, a comparison was made of two developmental versions of the program, one using the approximation technique, the other using tabulated values of sun (x, y, z) taken directly from the almanac. Entering and leaving times agreed exactly.

Function Cards and Results

* SHADOW 1136 6 20 20 0 0.0 6 24 0 0 0.0

VEH 1136 RUN NO. TST11MAY

SHADOW INTERVALS TABULATED BELOW

ENTER							LEAVE					
MO	DY	HR	MN	SEC	SYSTEM	REV	HR	MN	SEC	SYSTEM	REV	DURATION
		⋮			(Table Look-up Version)			⋮				
6	21	12	30	30.	45030.	11.7	13	7	24.	47244.	12.1	2214.
6	21	13	59	10.	50350.	12.7	14	36	4.	52564.	13.1	2214.
6	21	15	27	49.	55669.	13.7	16	4	43.	57883.	14.1	2214.
6	21	16	56	29.	60989.	14.7	17	33	23.	63203.	15.1	2214.
6	21	18	25	8.	66308.	15.7	19	2	2.	68522.	16.1	2214.
6	21	19	53	48.	71628.	16.7	20	30	42.	73842.	17.1	2214.
6	21	21	22	27.	76947.	17.7	21	59	21.	79161.	18.1	2214.
		⋮			(Sine Curve Approximation Version)			⋮				

ENTER							LEAVE					
MO	DY	HR	MN	SEC	SYSTEM	REV	HR	MN	SEC	SYSTEM	REV	DURATION
6	21	12	30	30.	45030.	11.7	13	7	24.	47244.	12.1	2214.
6	21	13	59	10.	50350.	12.7	14	36	4.	52564.	13.1	2214.
6	21	15	27	49.	55669.	13.7	16	4	43.	57883.	14.1	2214.
6	21	16	56	29.	60989.	14.7	17	33	23.	63203.	15.1	2214.
6	21	18	25	8.	66308.	15.7	19	2	2.	68522.	16.1	2214.
6	21	19	53	48.	71628.	16.7	20	30	42.	73842.	17.1	2214.
6	21	21	22	27.	76947.	17.7	21	59	21	79161.	18.1	2214.

8.7 Conclusions

The analysis shows favorable results, and net accuracy at least as good as one minute. One clue that it might be considerably better is afforded by the DURATION, which during peak shadow periods does not vary by a second, and which varies monotonically and regularly through those periods when the shadow period is changing more rapidly. That is, not more than a second or two random "jitter" is noted.

9.0 REFERENCES

9.1 American Ephemeris and Nautical Almanac, issued by Naval Almanac Office US Naval Observatory, US Government Printing Office.

9.2 1604 Systems Manual, TM-705/000/00, System Development Corporation, 25 April 1963.

9.3 TM-1124/000/00, Milestone 4, (SHADOW), System Development Corporation, 22 March 1963.

10.0 DETAILED FLOW CHARTS (Underlined caps are program tags.)

10.1 Main Program

```
           ENTER
             |
SHADOW   Save Index Registers
             |
         Read R file from Reset Tape
             |
         Print Vehicle and Run numbers, and headers
             |
         Rev no. input? - Yes--->Using LTT, Set WHISTLE and Start times from
             |                                                  rev number
             NO                                                     |
             |                                                      |
         Set Universal time, get machine time                       |
             |                                                      |
         Set WHISTLE = quitting time                                |
             |                                                      |
         Set TAU = start time                                       |
             |                                                      |
             |    +-------------------------------------------------+
             |    |
HKEEP    Clear TAUTOTAL, Compute PER/8
             |
         Set TAUSTART = TAU
             |
         Compute XBASE, YBASE for this year
             |
SEARCH   Set XR 6 = 0
             |
         In sunshine this t? - NO--->Set XR 6 = 1 for two passes through SEARCH
             |                                           to get a better TAUIN
            YES                                                        |
             |                                         +-----------+   |
INCR3    Increase TAU by one minute to establish        |           |   |
         direction (toward or away from x', y', z')     |      to STSHAD
             |                                          |
         In sunshine this t? - NO-----------------------+
             |
            YES
             |
         to  |
             |
           INCR
```

INCR Increase TAU by 1/8 period

Check for done (DONECHCK Subroutine)

In sunshine this t? - NO

YES

Are we getting closer to x', y', z' ?

YES NO

Had we been getting closer?

NO YES

FINER Decrease TAU by PER/8

Set DIFF2 via COMPUTE

INCR1 Store modified TAU

Sunshine this t? - NO

YES

Getting closer? - NO → PRNODATA (Subroutine)

YES

INCR4 Increase TAU by One Minute

to **SEARCH**

STSHAD Save entering times

INCR2 Increase TAU by one minute (First time, step through shade in one minute increments)

Sunshine this t?

NO YES

Set TAUOUT = TAU

Print one line of data

Did we start in shadow?

YES NO

to **INCR** to **CYCLE**

<u>CYCLE</u> Set TAU = TAUIN + period - one minute

Check for done (DONECHECK)

Sunshine this t? - NO

YES

<u>INCRE</u> Increase TAU by one minute

Sunshine this t? - NO

YES

Are we getting closer to (x',y',z')?

YES NO

PRNODATA Subroutine

to <u>SEARCH</u>

<u>SHADE</u> Decrease TAU by one minute

Sunshine this t?

NO YES

<u>INCRE1</u> Increase TAU by one second

Sunshine? - NO

YES Save entering times (SAVE subroutine)

Set TAU = TAUIN plus last DURATION (TAUDUR)

<u>INCRE2</u> Store modified TAU

In sunshine this t? - NO

YES <u>SHADE1</u> Increase TAU by one second

Decrease TAU by one second

In sunshine this t?

NO YES

Print one line of data

to <u>CYCLE</u>

DETAILED FLOW CHARTS (Cont'd)

10.2 COMPUTE SUBROUTINE

The inputs to this subroutine are TAU, X, Y, Z, and the inertial coordinates of the sun. The outputs are:

UCDSQ = D^2, where D is the distance from (x',y',z') to the satellite.

LCDSQ = d^2, where d is the distance from (x',y',z') to the border of the shadow.

DIFFNOW = $(D^2 - d^2)$. If negative, satellite is in shadow.

DIFFLAST = $(D^2 - d^2)$ for the previous entry to this subroutine.

DIFF2 = (DIFFNOW - DIFFLAST), or $(D_n^2 - D_{n-1}^2)$ for two successive subroutine executions.

LSTDIFF2 = Previous value of DIFF2.

(These "second differences" are used in the SEARCH portion of the program, which locates initial shadow boundaries. They are also essential to the logic which determines that, for a given rev, shadow interval less than 60 seconds.)

Enter Subroutine
↓
Compute Universal Time
↓
Set DIFFLAST and LSTDIFF2
↓
Compute elements this TAU (TTE)
↓
Convert to rectangular (PTR)
↓
Compute RHOSQ, radius squared of sphere containing satellite.
↓
Compute time of year in hours, call it HANGLE
↓
HANGLE < XBASE? - YES → AA10 Divide by XPERN
↓
NO
↓
HANGLE > XBASE + XPER ? YES → BB10 Divide by XPERN1
↓
NO
Divide by XPER

Multiply by II

Multiply by II to convert to radians

Add II, converting HANGLE to radians
↓
Store as XANGLE for checkout purposes
↓

↓
Fetch Cosine this angle
↓
Subtract fudge constant
↓
Convert to feet
↓
Store as SUNX
↓
Accumulate range of sun (squared)
↓
Similarly, from HANGLE compute YZANGLE in radians
↓
Fetch sine this angle
↓
Negative ? - YES Normalize by YNORMN
↓
NO
↓
Normalize by YNORMP
↓
Convert to feet
↓
Store as SUNY
↓
Accumulate range of Sun (squared)
↓
Similarly, compute SUNZ
↓
Compute range of sun
↓
Compute x',y',z'
↓
Compute UCDSQ and LCDSQ
↓
Set DIFFNOW, DIFF2, leave DIFFNOW in accumulator
↓
Exit

DETAILED FLOW CHARTS (cont'd)

10.3 PRDATA Subroutine

This subroutine is entered whenever the satellite leaves shadow. It prints on- and off-line the times of entering and leaving, the latitude/longitude of the subpoint at these times, and the duration of time in shadow.

```
Enter Subroutine
    ↓
Set up output
    ↓
Print on-line
    ↓
Print off-line
    ↓
Exit
```

DETAILED FLOW CHARTS (cont'd)

10.4 SAVE Subroutine

This subroutine saves time and position when the satellite enters shadow.

Enter Subroutine
↓
Store desired values of time
↓
Set up for LATLONG subroutine
↓
Compute and store latitude and longitude for printout
↓
Exit

DETAILED FLOW CHARTS (cont'd)

10.5 DONECHCK Subroutine

This subroutine is entered when TAU is incremented, to check for "done". If so, a Summary printout is presented showing per cent of time in shadow.

```
Enter Subroutine
  ↓
TAU < WHISTLE? - YES ——→ Exit
  ↓
  NO
  ↓
Print per cent time in shadow
  ↓
Reset Index Registers
  ↓
Return to COP
```

DETAILED FLOW CHARTS (Con't.)

10.6 DECAY SUBROUTINE

This subroutine is entered when RAD $\leq$ Earth radius, implying that the bird has come down.

Enter Subroutine
↓
Print on-line ORBIT HAS DECAYED
↓
Print summary, reset Index registers
↓
Return to COP

DETAILED FLOW CHARTS (Cont'd)

10.7 LATLONG SUBROUTINE

This subroutine computes geodetic latitude and longitude in degrees and minutes and sets up one part of a two-part table, corresponding to entering and leaving, depending upon index register 4, which is preset to zero for entering and six for leaving.

Enter Subroutine
↓
Set Character for North or South latitude
↓
Convert to geodetic, degrees and minutes
↓
Store in table for output
↓
Set character for East or West longitude
↓
Convert to degrees, minutes
↓
Store in table for output
↓
Exit

DETAILED FLOW CHARTS (Cont'd)

10.8 PRNOSHAD SUBROUTINE

This subroutine is entered whenever the shadow period was less than sixty seconds for a given rev. It prints an appropriate comment on-line.

Enter Subroutine
↓
Print REV XX. SHADOW PERIOD LESS THAN ONE MINUTE
↓
Exit

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System Development Corporation,
Santa Monica, California
SATELLITE COMPUTER PROGRAM DESCRIPTION
MILESTONE 5 COMPUTE SHADOW TIMES (SHADOW).
Scientific rept., TM(L)-1272/000/00,
by C. M. Seacat, L. M. Cranston.
22 May 1963, 32p.
(Contract AF 19(628)-1648, Space Systems
Division Program, for Space Systems
Division, AFSC)
Unclassified report

DESCRIPTORS: Programming (Computers).
Satellite Networks.

UNCLASSIFIED

Reports that SHADOW is a 1604 COP-controlled program to compute the times at which a satellite enters and leaves the shadow of the earth. Also reports that results are printed on-line and off-line.

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